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**RESEARCH AND DEVELOPMENT
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NONSTRUCTURAL MATERIALS**

**Delivery Order 0001: Study of Hydraulic
System Component Storage with Operational
and Rust-Inhibited Hydraulic Fluids**



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This technical report has been reviewed and is approved for publication.

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14. ABSTRACT In this program, bearings and pistons were stored in jars containing both operational hydraulic fluids (MIL-PRF-83282, MIL-PRF-87257 and MIL-PRF-5606) and rust inhibited hydraulic fluids containing BSN (MIL-PRF-46170 and MIL-PRF-6083). In addition, hydraulic pumps were filled with MIL-PRF-83282, MIL-PRF-87257 and MIL-PRF-46170. Jars, containing bearings and pistons, as well as hydraulic pumps were stored for up to 3 years in a laboratory environment to determine if operational fluids would protect them from rusting during storage. After each year, the bearings, pistons, and pumps were inspected for corrosion. At the end of 3 years of storage, pumps were endurance tested using fresh operational fluid, MIL-PRF-83282. The bearings, pistons and pumps showed no rusting for the duration of storage with either operational or storage fluids. The pumps stored with the operational fluids MIL-PRF-83282 and MIL-PRF-87257 were in better condition than the pump stored with the rust inhibited fluid. The operational hydraulic fluids MIL-PRF-83282 and MIL-PRF-87257 provided excellent protection against rusting during storage.						
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Study of Hydraulic System Component Storage with Operational and Rust-Inhibited Hydraulic Fluids

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ABSTRACT

In the military aerospace community, most hydraulic fluid pumps and components are currently being stored in rust inhibited fluids containing barium dinonylnaphthalene sulfonate (BSN). Fluids containing barium are hazardous waste, have expensive disposal, and have caused operational problems in aircraft hydraulic systems including helicopters and fighter aircraft. In this program bearings and pistons were stored in jars containing both operational hydraulic fluids (MIL-PRF-83282, MIL-PRF-87257 and MIL-PRF-5606) and rust inhibited hydraulic fluids containing BSN (MIL-PRF-46170 and MIL-PRF-6083). In addition, hydraulic pumps were filled with MIL-PRF-83282, MIL-PRF-87257 and MIL-PRF-46170. Hydraulic pumps were not filled with MIL-PRF-5606 or MIL-PRF-6083 because these hydraulic fluids are being phased out of military aerospace applications as operational and storage fluids, respectively. Jars, containing bearings and pistons, as well as hydraulic pumps were stored for up to three years in a laboratory environment to determine if operational fluids would protect them from rusting during storage. After each year the bearings, pistons, and pumps were inspected for corrosion. At the end of three years of storage, pumps were endurance tested using fresh operational fluid, MIL-PRF-83282. The bearings, pistons and pumps showed no rusting for the duration of storage with either operational or storage fluids. The pumps stored with the operational fluids, MIL-PRF-83282 and MIL-PRF-87257, were in better condition than the pump stored with the rust inhibited fluid. The operational hydraulic fluids, MIL-PRF-83282 and MIL-PRF-87257 provided excellent protection against rusting during storage.

BACKGROUND

The Department of Defense (DoD) generates considerable used hydraulic fluid waste in the operation and maintenance of aircraft. In the Air Force, used hydraulic fluid is the second largest waste stream, after aircraft painting waste. Table 1 identifies the various hydraulic fluids used in this study. The waste from fluids containing barium dinonylnaphthalene sulfonate (BSN) we believe is unnecessary and should be eliminated. Its use traces back to a long standing tradition, as described in military technical orders, of using rust inhibited hydraulic fluid for the shipment and storage of components. As directed in earlier versions of Air Force Technical Order 42B2-1-3[1], when a component

is needed, it is removed from the shelf, the rust inhibited hydraulic fluid is drained and discarded, and then the component is installed. (Note: Since this study was completed, T.O. 42B2-1-3 was amended to allow for the use of operational fluids for component storage with aircraft System Program Office approval.) The rust inhibited fluids contain about 1500 ppm barium, in the form of BSN, an additive that the operational fluids do not have. The Environmental Protection Agency limit for water-soluble barium for hazardous disposal is 120 ppm [2,3].

In rust inhibited fluid disposal, the barium content makes this fluid a hazardous waste material, requiring significantly greater handling and disposal expense compared to the operational fluids.

The justification for using rust inhibited hydraulic fluid for component storage goes back beyond the memory of the current military hydraulic fluids experts. In 1995, a group from WL/MLBT (now AFRL/MLBT), an aircraft System Programs Office (SPO) and an Air Logistics Center submitted a suggestion on an AF Form 1000 to use MIL-H-83282 [4] operational hydraulic fluid, rather than the rust inhibited fluids, for component storage. This came about after a series of meetings and some in-house rust tests at WL/MLBT to answer the concerns of the SPO about removing, storing, and re-installing armaments on the aircraft and the rust inhibited fluid waste stream these actions would generate. Ultimately, the prime contractor, with the SPO concurrence, decided to avoid the use of rust inhibited fluid for storage of armaments when removed from the aircraft. (Technical Orders for this aircraft have not yet been generated.) Some other aircraft also have never used rust inhibited fluid, but have used the operational fluid for shipping and storing the aircraft components. In response to the suggestion, all but one responder agreed the elimination of rust inhibited fluids was a good idea, but none of the responders believed he had the authority to change the status quo. In a response from the objecting SPO, there was considerable concern that using storage fluids was necessary; "No testing is known to have determined how fast ...corrosion commences in the aircraft hydraulic fluid parts using MIL-PRF-83282." This was a true statement and is the subject this program addressed.

Besides the waste stream issue generated by the use of storage fluid, two recent experiences point to the rust inhibitor causing aircraft operational problems. In the first case, helicopters were grounded because of valve sticking. AFRL/MLBT found analytical evidence of the decomposition of the rust inhibitor additive on the valve surfaces. A follow-on study reproduced the decomposition product in AFRL in-house laboratory experiments; validating the hypothesis that residual rust inhibitor (as low as 15 ppm barium) caused the sticking valve problem [5]. The helicopter maintainers were unaware the rust inhibited fluid was supposed to be drained from components before installation onto the aircraft and were omitting that step. Elimination of rust inhibited hydraulic fluid from the helicopter hydraulic system solved the operational problem.

In the second case a fighter aircraft was experiencing premature filter clogging and rapid pump wear. Excessive rust inhibitor fluid, along with several other unique factors, was found to be the cause. In both of these cases, we suspect the desire to reduce the maintenance burden and minimize waste stream at bases contributed to the problem. Because the storage fluid and operational fluids are not obviously different (both are dyed red), field maintenance personnel may assume there is no harm in leaving storage fluid in the components before installation. Also in some complex components it is impossible to

drain out very much of the storage fluid. However, the storage fluid is only thermally stable to 225°F while operational fluids are stable to 275°F, for MIL-PRF-5606 [6], and to 400°F for MIL-PRF-83282 and MIL-PRF-87257 [7]. Storage fluids, specifically those containing the BSN additive, will decompose over 225°F.

As hydraulic systems' operational temperatures are raised and more demands are placed on them, more operational problems from contamination from the less stable rust inhibited storage fluid are predicted. In addition, the waste stream from storage fluid, properly drained from stored components, is expensive.

EXPERIMENTAL

This program came out of the need for proof that hydraulic components could be stored in operational fluids without risk of the components rusting on the shelf. It was decided to set up real time storage tests, up to 3 years. All tests were at ambient laboratory temperature and relative humidity conditions and the temperatures and relative humidity were recorded.

Bearing and Piston Jar Storage Test

In one set of tests, jars were used. Two sets of jars were filled with the test fluids containing different concentrations of water. In one set of those jars, no components were placed to investigate what happens to the added water during the storage period. In another set of jars, in each jar were placed a 52100 tapered roller bearing (from the Timken Bearing Company) and a used piston from an F-16 hydraulic pump. A photograph of the setup is located in Appendix A. Contaminating the fluid with water for these storage tests represented severe storage conditions. In the third set of jars, the components were stored after being soaked in fluids containing water and drained for ten seconds. The bearing and piston jar storage test matrix is described in Table 2.

The bearings were cleaned by a procedure supplied by the Timken Bearing Company. Bearings were brushed thoroughly in hexane and were handled with tongs for the remainder of the cleaning procedure. The bearings were then washed in hot, 125-150°F, hexane followed by a second wash in a fresh hot hexane. Bearings were rinsed twice in a fresh solvent solution containing 90% A.C.S. grade isopropyl alcohol, 9% deionized water, and 1% reagent grade ammonium hydroxide. Bearings were placed on clean filter paper to drain. The bearing were dried in an oven at 220°F for 15-30 minutes and stored in a desiccator to cool to room temperature. The dry bearings were analyzed by grazing angle Fourier transform infrared microscopy (GA FT-IR) to ensure that residual preservative fluid and organic material had been cleaned from the bearings. The cleaned bearings were photographed, documenting as much surface as possible. The bearings were re-examined and photographed yearly for any visual corrosion.

MIL-PRF-5606, MIL-PRF-83282, and MIL-PRF-87257 were prepared to contain 80-100 ppm and 350 ppm water. MIL-PRF-46170 [8] and MIL-PRF-6083 [9] were prepared to contain ~220 ppm and 400 ppm water. (Note: The US Army as the MIL-PRF-46170 custodian had cancelled MIL-PRF-46170 Type II, the aircraft component storage fluid, which was used in these experiments.) These levels of water contamination, although different for the different hydraulic fluids, were selected so that the total water content of each fluid was approximately 50 ppm below the saturation level for that fluid.

Eight jars were used for each fluid with the lower water contamination level. Four of these were filled with a bearing, a piston, and 100 ml of contaminated fluid. The next four were filled with 100 ml of contaminated fluid only as shown in Table 3.

Twelve jars were used for each fluid with the higher contamination level. The first two sets of four were set up in the same way as for the lower water contamination fluid, drained for ten seconds, and placed in the third set of four empty jars to represent a soak and drain condition.

The top of the piston was wetted with fluid by tipping the jar. All jars were capped tightly prior to storage. All specimens were visually examined every month without opening the jars. After each year of storage, one bearing and piston were removed and inspected from one jar of each set of four. The fluid was examined for debris. Water content was measured in one of the fluid jars for each fluid/water contamination level after three years.

If corrosion existed, the surface was analyzed by GA FT-IR microscopy.

Pump Storage and Pump Tests

Three hydraulic pumps were stored for three years, each filled with different test fluid as shown in Table 4. Water was added to the test fluids to simulate severe storage conditions. The pumps used were the Vickers model PV3-075-15, which is a typical axial flow piston pump used in aircraft. Before storage and after every year, each pump was disassembled and the internal parts inspected, changes documented and photographed. Karl Fisher Titration, ASTM D 6403 [10] was used to measure the water level in the test fluid at the yearly inspection. If necessary, water was added to return the fluids to their original water concentration. Then each pump was reassembled and returned to storage. At the end of three years, after the final inspection, the MIL-PRF-83282-pump and MIL-PRF-87257-pump were drained and then filled with MIL-PRF-83282. The post-storage performance of the pumps was validated in a 500-hour endurance pump test using the conditions and procedure described below.

Pump Test Conditions:

Pump Shaft Speed:	5000 rpm
Pump Inlet Pressure:	70 psig
Pump Outlet Pressure:	3000 psig
Max Fluid Temperature:	255°F
Pump Outlet Flow:	Cycle between 12.5 gpm and 3 gpm every minute
Test Duration:	500 hours or performance degradation, whichever occurs first

The test stand was filled with fresh MIL-PRF-83282 and any entrained air was bled out. This initial charge of fluid was used throughout the test and no make-up fluid was added. A 50 ml fluid sample was taken at zero hours (immediately following bleeding). The pump was started under low load (~ 3 gpm main flow) and the speed increased to 5000 rpm at low load. Within one minute the automatic throttling valve cycling was activated to alternate the main flow between 12.5 and 3 gpm every minute. The maximum case drain temperature was stabilized to 250-255°F. Fluid samples were taken

at 50 and 100 hours and at every 100-hour increment thereafter. At 500 hours, a 150 ml fluid sample was taken and the test stopped. The pump was disassembled, inspected, and photographed. The filter elements and fluid from the test were retained.

The MIL-PRF-46170-pump was not tested but would have been if either the MIL-PRF-83282-pump or the MIL-PRF-87257-pump had failed due to fluid degradation.

RESULTS

Fluid Only Jar Storage

Water level tended to decrease to a certain level depending on the fluid. MIL-PRF-5606 decreased to ~50 ppm water probably because it is relatively nonpolar in nature. MIL-PRF-83282 and MIL-PRF-87257 decreased to 100-150 ppm water due to these fluids containing about 33% ester, which helped solubilize the water in the hydraulic fluid. MIL-PRF-6083 and MIL-PRF-46170 reached ~690 and 600 ppm water respectively due to the hygroscopic nature of the BSN additive. The water levels in all of the other storage tests followed these same trends. See Table 3 for data. Inspection of the bearings revealed no corrosion.

Bearing and Jar

Operational Fluids

The bearings and pistons stored in MIL-PRF-83282, MIL-PRF-87257, and MIL-PRF-5606 fluids exhibited no evidence of corrosion throughout the 3-year period of testing for both water contamination levels. See Table 5. The dip and drain bearings and pistons from these fluids also showed no evidence of corrosion. There was no change in the appearance of any of the fluids. Photographs of the bearings and pistons are found in Appendix B.

Rust Inhibited Fluids

The bearings and pistons stored in the jars containing MIL-PRF-46170 showed no evidence of corrosion at 1 year, but had dark bands on the outer race between the bearing contact areas for both water contamination levels for years 2 and 3. The initial and final water concentrations are shown in Table 5. Water content was not measured during year 1 and 2. The bearings and pistons stored in MIL-PRF-6083 showed no evidence of corrosion for the duration of the test. Photographs of the bearings and pistons stored in rust inhibited fluids are found in Appendix B.

Pump Storage and Pump Tests

Inspection after one-year storage

MIL-PRF-83282-Pump

Pre-storage pump photographs are in Appendices C, D and E. After one year all parts appeared identical to pretest inspection and free of corrosion. The pump was reassembled to proper specifications including lock-wire installation and refilled with fluid for further storage. See Appendix F.

MIL-PRF-87257-Pump

All parts appeared identical to pretest inspection and free of corrosion. The pump was reassembled to proper specifications including lock-wire installation and refilled for further storage. See Appendix G.

MIL-PRF-46170-Pump

Most of the parts appeared identical to pretest inspection. Red gel and colorful banded staining was found on the balls of the main shaft bearing. The pattern created appears to involve the bearing cage. The photographs are shown in Appendix H. The bearing exhibited slight hesitation to free rotation of the outer race when turned by hand. No other abnormal features were observed. The pump was reassembled to proper specifications including lock-wire installation and refilled for further storage.

Inspection after two-year storage

MIL-PRF-83282-Pump

All parts appeared identical to pretest inspection and free of corrosion. The pump was reassembled to proper specifications including lock-wire installation and refilled for further storage.

MIL-PRF-87257-Pump

All parts appeared identical to pretest inspection. The bearing exhibited slight hesitation to free rotation of the outer race when turned by hand. The pump was reassembled to proper specifications including lock-wire installation and refilled for further storage.

MIL-PRF-46170-Pump

Most of the parts appeared in good condition and free of corrosion. The main shaft bearing had deteriorated in rolling smoothness, and definite rotational roughness was easily felt. The appearance of the bearing balls has changed since the previous year, from colorful banding on a reduced luster surface to an even, colorless dullness without differentiation over the complete ball surface. The tapered area above the gimbal joint of the piston/shoe assembly had a ruddy tarnish not seen before in this pump. This area never contacts other metals, but is exposed only to fluid. No other abnormal features were observed. Photographs are in Appendix I. The pump was reassembled to proper specifications including lock-wire installation and refilled for further storage.

Inspection after three-year storage

The third year inspections showed no notable changes for any of the pumps between the second and third years.

Endurance Pump Tests after three-year storage

The following performance parameters were monitored during the pump tests:

Flow Rates:	pump outlet and pump case drain
Pressures:	pump outlet and pump case drain
Fluid Temperatures:	pump outlet, pump case drain and pump inlet

Heat Rejection Rate:	coolant flows and heat exchanger temperature differential
Torque:	electric drive motor torque

The fluid samples taken during the pump tests were analyzed per the methods in Table 6.

MIL-PRF-83282-Pump Test

This test successfully completed 511 hours. The post-test inspection revealed no excessive wear or corrosion of the pump parts. The data in Tables 7 show that this fluid was in excellent condition throughout the test. Inductively coupled plasma spectroscopy was conducted to follow the wear and other metal trends for Al, Cu, Mg, Mn, Na, Fe, Ni, Zn, Si, Sn, Cd, Ag, Mo, Ca, B, Ba, Pb and Cr. All metals were below the detection limit of 1 ppm.

MIL-PRF-87257-Pump Test

This test was stopped at 275 hours due to catastrophic failure of one piston shoe, unrelated to storage in the operational fluid, which has been attributed to manufacturing defects in the shoe. The shoe material is bronze and not subject to corrosion by water. There was no evidence of corrosion on the shoe when the test was stopped. This shoe failure mode was also documented in earlier pump tests in this laboratory using the same model pump but preserved in MIL-PRF-46170 before testing. The data in Tables 8 show that this fluid was in excellent condition throughout the test. This pump test was successful in demonstrating the performance capabilities for the specimen pump were still intact after storage in the contaminated operational fluid up to the point of the shoe failure, and these capabilities were equivalent to other identical new pumps that are preserved with uncontaminated MIL-PRF-46170. Inductively coupled plasma spectroscopy was conducted to follow the wear and other metal trends for Al, Cu, Mg, Mn, Na, Fe, Ni, Zn, Si, Sn, Cd, Ag, Mo, Ca, B, Ba, Pb and Cr. All metals were below the detection limit of 1 ppm.

DISCUSSION

The operational fluids performed as well as or better than the rust inhibited storage fluids for all experiments performed here. The bearings and pistons stored in MIL-PRF-83282, MIL-PRF-87257, MIL-PRF-5606, and MIL-PRF-6083 exhibited no corrosion for the duration of the test. The bearings and pistons stored in MIL-PRF-46170 showed the most significant change as there were dark bands on the race and the bearing contact area that could not be removed by cleaning with solvent. The pump storage showed similar results.

The pump test results, summarized in Table 9, showed the MIL-PRF-83282 and the MIL-PRF-87257 to be excellent storage fluids. The pump stored with MIL-PRF-83282 passed the pump test with 511 hours and no signs of fluid degradation. In the pump stored with MIL-PRF-87257, a piston shoe failed at 275 hours but there were no signs of fluid degradation. It is believed that the fluid in which the pump was stored did not cause this failure. In order to verify this assumption, two pumps were put into storage containing MIL-PRF-87257 with 300 ppm water and will be treated the same as the pump that failed after 275 hours.

CONCLUSIONS

1. The operational fluid MIL-PRF-5606 performed as well in bearing and piston jar storage as the rust-inhibited storage fluid, MIL-PRF-6083, that is used in combination with it.
2. Operational fluids MIL-PRF-83282 and MIL-PRF-87257 performed better than their companion rust inhibited storage fluid MIL-PRF-46170 in bearing and piston jar storage.
3. Pump storage showed the pumps stored containing operational fluids MIL-PRF-83282 and MIL-PRF-87257 did not corrode and were in better condition than the pump stored in MIL-PRF-46170.
4. Pump tests demonstrated that storing the pumps with operational fluids has no adverse effects on the performance of the pumps or the condition of the hydraulic fluid.
5. Storing the pumps with operational fluid eliminates the high cost associated with disposing the barium containing rust inhibited fluid.
6. Storing the pumps in operational fluid also eliminates the problems caused when the rust inhibited storage fluid is not properly drained from the hydraulic system components.

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Table 1. Military Hydraulic Fluids

Fluid	Base Fluid	Rust Inhibited	Low Temperature Use Limit, °F (°C)
MIL-PRF-83282	PAO ¹	No	-40 (-40)
MIL-PRF-87257	PAO ¹	No	-65 (-54)
MIL-PRF-46170	PAO ¹	Yes	-40 (-40)
MIL-PRF-5606	Mineral Oil	No	-65 (-54)
MIL-PRF-6083	Mineral Oil	Yes	-65 (-54)

1. Hydrogenated polyalphaolefin

Table 2. Bearing and Piston Jar Storage

Test Fluid	H ₂ O	Fluid Quantity in Jar	Parts in Jar
	ppm	ml	
MIL-PRF-83282	80-100	100	None
MIL-PRF-83282	80-100	100	Bearing and Piston
MIL-PRF-87257	80-100	100	None
MIL-PRF-87257	80-100	100	Bearing and Piston
MIL-PRF-5606	80-100	100	None
MIL-PRF-5606	80-100	100	Bearing and Piston
MIL-PRF-83282	350	100	None
MIL-PRF-83282	350	100	Bearing and Piston
MIL-PRF-83282	350	None *	Bearing and Piston
MIL-PRF-87257	350	100	None
MIL-PRF-87257	350	100	Bearing and Piston
MIL-PRF-87257	350	None *	Bearing and Piston
MIL-PRF-5606	350	100	None
MIL-PRF-5606	350	100	Bearing and Piston
MIL-PRF-5606	350	None *	Bearing and Piston
MIL-PRF-46170	220	100	None
MIL-PRF-46170	220	100	Bearing and Piston
MIL-PRF-6083	220	100	None
MIL-PRF-6083	220	100	Bearing and Piston
MIL-PRF-46170	400	100	None
MIL-PRF-46170	400	100	Bearing and Piston
MIL-PRF-46170	400	None *	Bearing and Piston
MIL-PRF-6083	400	100	None
MIL-PRF-6083	400	100	Bearing and Piston
MIL-PRF-6083	400	None *	Bearing and Piston

* = Parts soaked in fluid and drained for 10 seconds
All experiments began with four jars

Table 3. Water Concentration Change in Fluid Only Jar Storage

Fluid	Initial H ₂ O ppm Goal (*)	End of Storage (ppm H ₂ O)		
		Year 1	Year 2	Year 3
MIL-PRF-5606	100 (87)	38	39	51
MIL-PRF-5606	350 (347)	37	41	52
MIL-PRF-83282	100 (106)	79	89	112
MIL-PRF-83282	350 (352)	78	89	112
MIL-PRF-87257	100 (96)	103	108	155
MIL-PRF-87257	350 (338)	111	117	157
MIL-PRF-6083	220 (241)	589	624	685
MIL-PRF-6083	400 (408)	581	615	694
MIL-PRF-46170	220 (215)	544	493	502
MIL-PRF-46170	400 (412)	519	496	512

* = Measured water value determined by ASTM D 6304

Table 4. Pump Storage

Test	Pump Model	Pump Serial No.	Test Fluid	Water Contamination ppm	Remarks
83282-Pump	PV3-075-15	MX-463744	MIL-PRF-83282	350	
87257-Pump	PV3-075-15	MX-500824	MIL-PRF-87257	350	
46170-Pump	PV3-075-15	MX-509181	MIL-PRF-46170	400	This pump has not been tested and is currently filled with MIL-PRF-83282

Table 5. End of Storage Changes in Bearings and Pistons

Fluid	Initial H ₂ O ppm goal (*)	Set-up type	End of storage results			
			Year 1 **	Year 2 **	Year 3	
			Part Description	Part Description	(ppm H ₂ O)	Part Description
MIL-PRF-83282	100 (106)	Soak	NC	NC	107	NC
MIL-PRF-87257	100 (96)	Soak	NC	NC	153	NC
MIL-PRF-5606	100 (87)	Soak	NC	NC	48	NC
MIL-PRF-6083	220 (241)	Soak	NC	NC	674	NC
MIL-PRF-46170	220 (215)	Soak	NC	***	511	***
MIL-PRF-83282	350 (352)	Soak	NC	NC	112	NC
MIL-PRF-87257	350 (338)	Soak	NC	NC	152	NC
MIL-PRF-5606	350 (347)	Soak	NC	NC	48	NC
MIL-PRF-6083	400 (408)	Soak	NC	NC	684	NC
MIL-PRF-46170	400 (412)	Soak	NC	***	513	***
MIL-PRF-83282	350 (352)	Dip & Drain	NC	NC	N/A	NC
MIL-PRF-87257	350 (338)	Dip & Drain	NC	NC	N/A	NC
MIL-PRF-5606	350 (347)	Dip & Drain	NC	NC	N/A	NC
MIL-PRF-6083	400 (408)	Dip & Drain	NC	NC	N/A	NC
MIL-PRF-46170	400 (412)	Dip & Drain	NC	***	N/A	NC

NC = No change in the appearance of the bearing or shoe

* = Measured water concentration determined by ASTM D 6304

** = Water content was only measured initially and in year 3 for the bearing and piston jars

*** = Had darkened bands on race and at the bearing contact surface areas, but no corrosion

N/A = Not applicable

Table 6. ASTM International Test Methods used to Determine Hydraulic Fluid Condition	
D 445 ¹¹	Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)
D 664 ¹²	Acid Number of Petroleum Products by Potentiometric Titration
D 892 ¹³	Foaming Characteristics of Lubricating Oils
D 4172 ¹⁴	Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method)
D 6304 ¹⁰	Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fisher Titration
D 5185 ¹⁵	Inductively Coupled Plasma Emission Spectroscopy (ICP)

Table 7. Characterization of Fluid Samples from MIL-PRF-83282-Pump Test

Hours	KF Water (ppm)	Acid Number (mg KOH /gm)	Vis@ 40°C (cSt)	Particulate Contamination	Foam	Four-Ball Wear Scar (mm)	
				NAS 1638/ Boeing-Navy Class	Pass/Fail	Run 1	Run 2
Fresh	88	0.0	14.31	9/5	pass	0.46	0.47
0	77	0.0	14.33	5/2	a	a	a
44	97	0.0	14.32	4/0	a	a	a
106	99	0.0	14.39	2/0	a	a	a
206	92	0.0	14.20	3/0	a	a	a
300	89	0.0	14.25	3/0	a	a	a
447	101	0.0	14.21	3/0	a	a	a
511	92	0.0	14.24	3/0	pass	0.46	0.47

a = Not determined

Table 8. Characterization of fluid Samples from MIL-PRF-87257-Pump Test

Hours	KF Water (ppm)	Acid Number (mg KOH /gm)	Vis@ 40°C (cSt)	Particulate Contamination	Foam	Four-Ball Wear Scar (mm)	
				NAS 1638/ Boeing-Navy	Pass/Fail	Run 1	Run 2
Fresh	58	0.0	14.28	1/0	pass	0.51	0.52
0	67	0.0	14.35	3/0	a	a	a
50	112	0.0	14.36	2/0	a	a	a
100	101	0.0	14.35	3/0	a	a	a
200	116	0.0	14.29	2/0	a	a	a
275	112	0.0	14.22	9/5	a	0.51	0.53

a = not determined

Table 9. Results of Three Year Pump Storage Tests

Storage Fluid	Storage Year 1	Storage Year 2	Storage Year 3	Pump Stand Results
MIL-PRF-83282	No corrosion	No corrosion	No corrosion	Passed at 511 hours.
MIL-PRF-87257	No corrosion	No corrosion	No corrosion	Failed at 275 hours due to piston malfunction not storage fluid
MIL-PRF-46170	Tarnish on bearing balls	Increased tarnish	No corrosion	Not tested because MIL-PRF-83282 and MIL-PRF-87257 fluids did not cause failure.

REFERENCES

1. U.S. Air Force Technical Manual, General, Fluids for Hydraulic Equipment, T.O. 42B2-1-3.
2. U.S. Environmental Protection Agency Handbook CFR, 261.24.
3. Military Aerospace Fluids and Lubricants Workshop Proceedings, AFRL-ML-WP-TP-2002-402, August 2002.
4. MIL-PRF-83282, Hydraulic fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, 30 Sept 1997.
5. Stuck Servovalves in Aircraft Hydraulic Systems, S.K. Sharma, L.J. Gschwender, Carl E. Snyder, Jr., J.C. Liang, B.S. Schreiber, Lubr. Eng., 55, 7, (1999).
6. MIL-PRF-5606, Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and ordnance, 7 June 2002.
7. MIL-PRF-87257, Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile, 22 April 2004.
8. MIL-PRF-46170, Hydraulic Fluid, Rust Inhibited, Fire Resistant Synthetic Hydrocarbon Base, Type II, 19 January 2001. (Cancelled)
9. MIL-PRF-6083, Hydraulic Fluid, Petroleum Base, for Preservation and Operation, 17 September 1997.
10. ASTM D 6403 Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fisher Titration, 2001 Annual Book of ASTM Standards (2001).
11. ASTM D 445 Standard Test Method for Determining Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity), 2001 Annual Book of ASTM Standards (2001).
12. ASTM D 664 Standard Test Method for Determining Acid Number of Petroleum Products by Potentiometric Titration, 2001 Annual Book of ASTM Standards (2001).
13. ASTM D 892 Standard Test Method for Determining Foaming Characteristics of Lubricating Oils, 2001 Annual Book of ASTM Standards (2001).
14. ASTM D 4172 Standard Test Method for Determining Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method), 2001 Annual Book of ASTM Standards (2001).

15. ASTM D 5185 Standard Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubrication Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Spectroscopy (ICP-AES), 2001 Annual Book of ASTM Standards (2001).

APPENDIX A
Initial Bearing and Piston Storage Picture



APPENDIX B
Component Jar After Storage Photographs
Dip and Drain



MIL-PRF-83282, 352 ppm H₂O



MIL-PRF-5606, 347 ppm H₂O



MIL-PRF-87257, 338 ppm H₂O



MIL-PRF-6083, 408 ppm H₂O



MIL-PRF-46170, 412 ppm H₂O

High Water Contamination



MIL-PRF-83282, 352 ppm H₂O



MIL-PRF-5606, 347 ppm H₂O



MIL-PRF-87257, 338 ppm H₂O



MIL-PRF-6083, 408 ppm H₂O



MIL-PRF-46170, 412 ppm H₂O

Low Water Contamination Levels



MIL-PRF-83282, 106 ppm H₂O



MIL-PRF-5606, 87 ppm H₂O



MIL-PRF-87257, 96 ppm H₂O

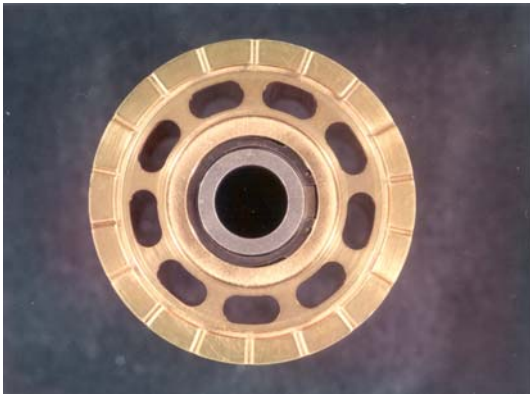


MIL-PRF-6083, 241 ppm H₂O



MIL-PRF-46170, 215 ppm H₂O

APPENDIX C **MIL-PRF-83282 Stored Pump Pre-storage Photographs**



Cylinder Block



Pintle Bearings, SC = case drain side



Piston Shoe Retaining Plate with Pistons



Pistons



Hold Down Plate Retainer - Steel



Hold Down Plate Retainer – Bronze Plated

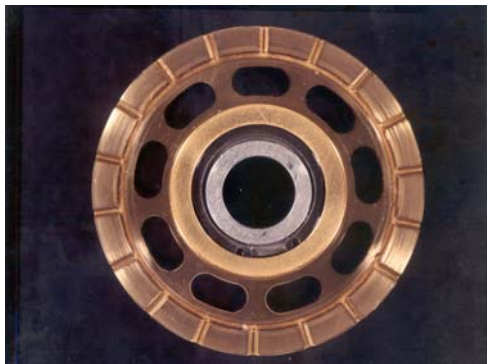


Compensator



Housing

APPENDIX D
MIL-PRF-87257 Stored Pump Pre-storage Photographs



Cylinder Block



Pintle Bearings, SC = case drain side



Piston Shoe Retaining Plate with Pistons



Pistons



Hold Down Plate Retainer - Steel



Hold Down Plate Retaining – Bronze Plated

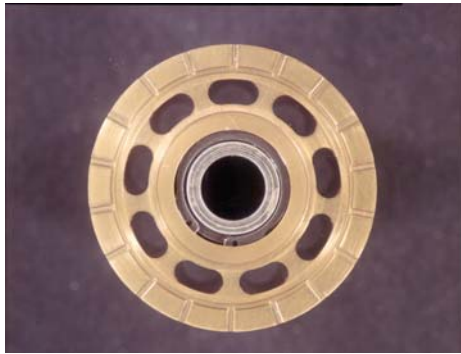


Compensator

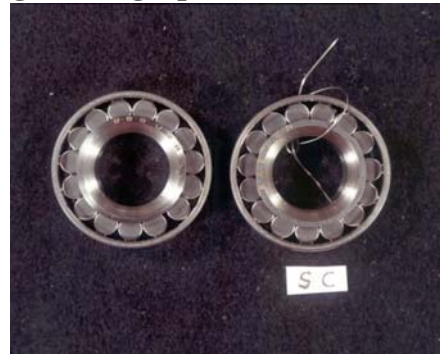


Housing

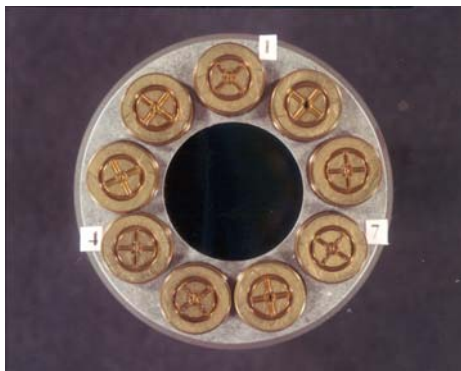
APPENDIX E **MIL-PRF-46170 Stored Pump Pre-storage Photographs**



Cylinder Block



Pintle Bearings, SC = case drain side



Piston Shoe Retaining Plate with Pistons



Pistons

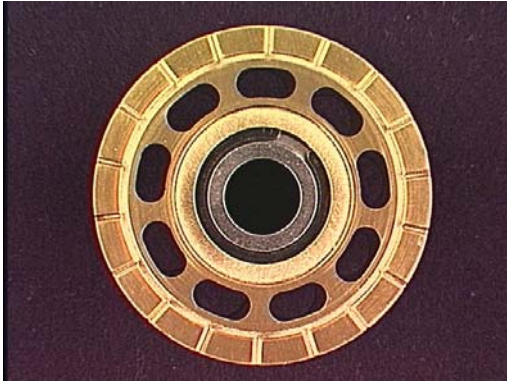


Hold Down Plate Retainer - Steel



Compensator

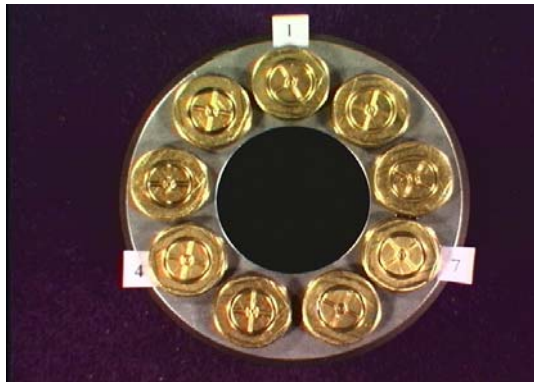
APPENDIX F
MIL-PRF-83282 Stored Pump Year 1 Photographs



Cylinder Block



Pintle Bearings



Piston Shoe Retaining Plate with Pistons



Pistons



Hold Down Plate Retainer - Steel

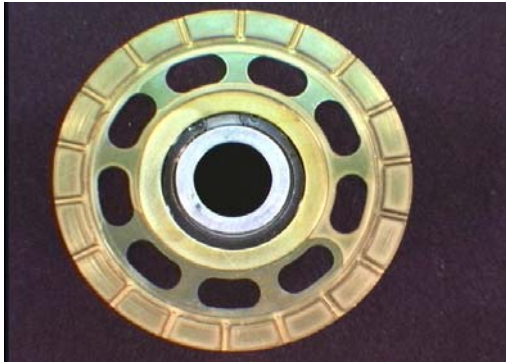


Hold Down Plate Retaining – Bronze Plated



Compensator

APPENDIX G
MIL-PRF-87257 Stored Pump Year 1 Photographs



Cylinder Block



Pintle Bearings, SC = case drain side



Pistons Shoe Retaining Plate with Pistons



Pistons



Hold Down Plate Retainer - Steel



Hold Down Plate Retainer – Bronze Plated

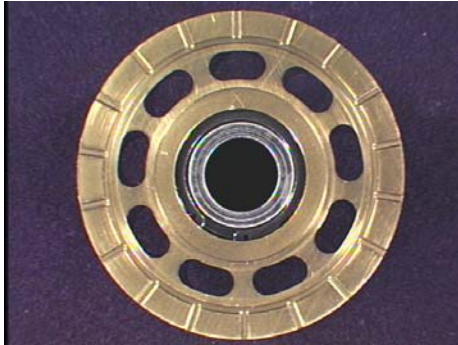


Compensator



Housing

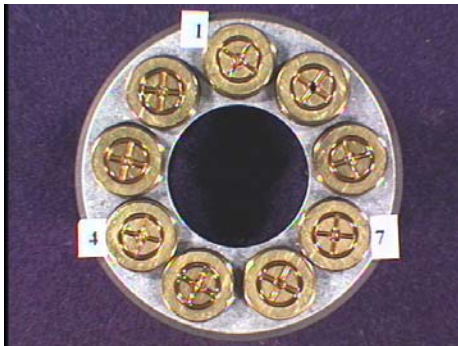
APPENDIX H
MIL-PRF-46170 Stored Pump Year 1 Photographs



Cylinder Block



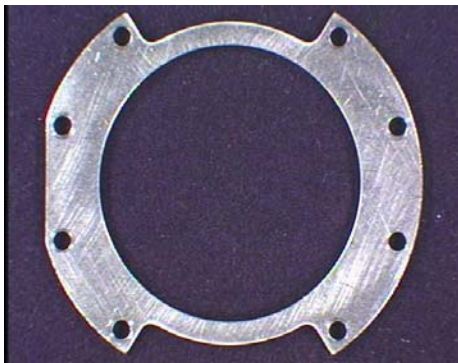
Pintle Bearing, SC = case drain side



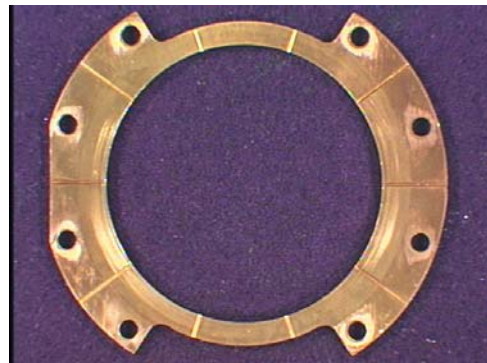
Piston Shoe Retaining Plate with Pistons



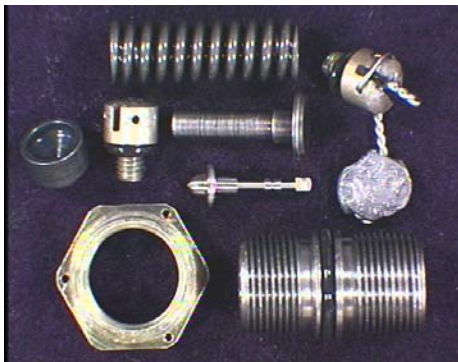
Pistons



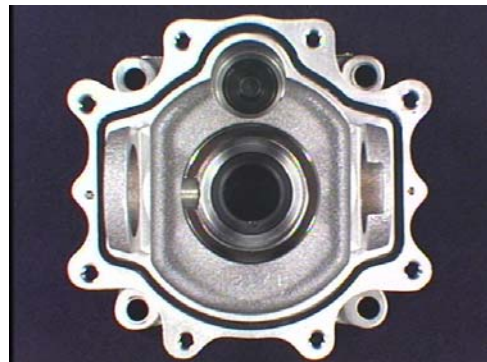
Hold Down Plate Retainer - Steel



Hold Down Plate Retainer – Bronze Plated

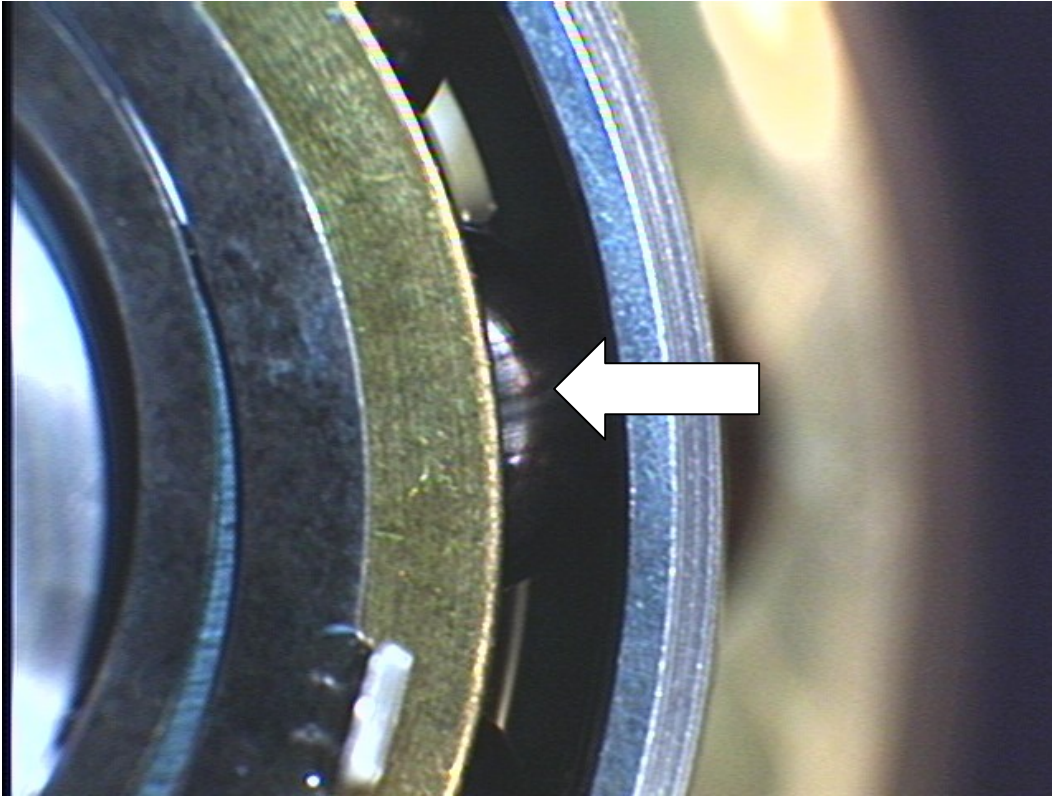


Compensator



Housing

The next picture is a close up of the main shaft bearing. Stripes were observed on the ball bearing. This phenomenon only occurred with this fluid.



APPENDIX I
MIL-PRF-46170 Stored Pump Year 2 Photographs



Cylinder Block



Pintle Bearing



Piston Shoe Retaining Plate with Pistons



Pistons – Note darkening of tapered area



Hold Down Plate Retainer - Steel



Hold Down Plate Retainer – Bronze Plated



Compensator



Housing

Below is an enlarged image of the pistons. The tarnish on the tapered section of the pistons is evident.

